ABSTRACT

After measuring ambient and peak noise and identifying significant contributors to operational noise levels in the initial phase of this project, this second phase research attempted to select and test suitable materials for their sound transmission loss (STL) capabilities and to design effective enclosures and barriers for containing or dampening noise levels in the host facility. The host facility was a southern Illinois coal handling plant containing vibratory screens, a rotary breaker, and multiple conveyor belts. Selected materials were tested at SIUC’s Acoustic Laboratory. SAE J1400 standards were followed in designing and adapting the testing procedure and experimental facility.

Laboratory research focused on measuring STL properties of various materials suitable for application in single- and double-barrier designs in the plant’s moist and dusty environment. Also, resistance to abrasiveness and ability to reduce transmission of impulse noise were examined. For these purposes, two experimental stands were designed and built. In the first one, data on generation and transmission of impulse noise were collected. This stand simulated plants conditions where kinetic energy impulses delivered by the impact of coal or rock masses impinging on a steel plate (as in the classical steel chute design) were converted into vibration signals and transmitted through the plate as peak noise. Samples of various noise-damping materials were tested individually and in tandem with other materials to identify those that provided the greatest reduction in transmitted impulse noise levels and their associated harmonics. In the second stand, data on resistance to abrasion and wear ability were collected. This sand blasting cabinet simulated transfer chutes in the plant where material flow erodes foundational structures and installed liners meant to protect those structures. Samples of various liners and foundational material were tested for durability and resistance to wear.

Both noise reduction and wear resistant testing identified the “Rock Plate” liner, a durable rubber embedded with ceramic components, as the material of choice for lining transfer chutes in the plant. This liner mounted on a steel framework created a single composite STL barrier. After installation, measured impulse (peak) noise was reduced from 127 to 114dB and steady noise around the chute’s exterior surface was on average 7dBA less. Compared to a bare steel plate, this material lasted approximately twice as long in laboratory abrasion test conditions. The next best material with high STL properties, a low density polypropylene, eroded several times faster than the steel plate.
EXECUTIVE SUMMARY

The first phase (ICCI Project Number 11/US-19) of this project involved industrial engineering and noise generation studies at the surface coal handling facility of an underground coal mine located in southern Illinois. Data collected on both character and values of noise generated in this particular facility showed that ambient average Sound (noise) Pressure Level (SPL), generated mainly by the largest equipment, depends on intensity of coal flow and rock content. The lowest SPL observed in selected locations oscillated around 99dBA for low intensity coal flow and reached 112dBA on average for maximum intensity coal flow. The noisiest equipment was the rotary breaker followed by vibratory screens. Impact noise, generated during conversion of kinetic energy into noise impulse when large pieces of coal and rock strike metal plates, reached 127dB. A large amount of low frequency noise was also observed.

These data were used to formulate suitable recommendations for noise reduction in the plant and establish research directions for this second phase of the project. The use of barrier materials to contain noise inside enclosures in this high-noise environment was the first priority. To reduce very high levels of noise, heavy-duty enclosures are required. Other techniques, such as double (or multiple) barrier systems or composite material designs are also useful. Effective barrier materials used for noise transmission loss applications have one basic common property – very high surface density and no porosity at all. High acoustical reflection coefficient is very desirable. The most effective barrier materials also have a high degree of internal damping related to apparent viscosity and negligible stiffness. They are commonly described as limp barrier materials. The parameter that describes the isolation or noise-stopping capability of a wall or panel of barrier material is the transmission coefficient (τ), which is used to calculate Sound Transmission Loss (STL). A number of prospective noise attenuating materials were tested for their STL at SIUC’s Acoustic Laboratory and those showing the highest STL were recommended for use.

These materials and others were also tested for their abrasion resistant properties. Results showed that ceramics are well-suited in applications where abrasion is a major factor. Ceramic plate wear was twice that of steel plate with comparable thickness.

To reduce high impact noise and increase resistance to abrasion in the host facility’s transfer chutes between vibratory screens and the rotary breaker, high STL panels with imbedded ceramic components were installed as liners creating a single composite barrier. Follow-up field measurements observed that transmitted impact (impulse) noise was reduced from 127dB to 114dBA and ambient (emitted) noise on the chute’s surface was decreased by approximately 7dBA in comparison with noise emissions from classical steel-only chute designs.
OBJECTIVES

The overall goal of this study was to recommend suitable measures to the host plant enabling them to reduce plant noise to acceptable levels for the long-term health and safety of plant personnel. Specific project objectives were:

- Design, build, and utilize two experimental stands to test various materials for their noise reduction capabilities and durability under simulated plant conditions. The first stand collected data on impact/impulse noise transmitted thru samples under controlled conditions of applied kinetic energy and impact direction. The second stand collected data on abrasion of samples under controlled amounts of kinetic energy and the direction of the abrasion stream impacting an investigated material.
- Collect data on STL for different configurations of noise attenuating materials and steel back plates including different combinations of composite materials. Initiate work on development of suitable noise reducing materials and systems for different applications in a coal handling facility.
- Use collected data to assist the engineering firm chosen by the host operation in redesigning and building new transfer chutes with the best possible noise reduction and resistance to erosion given the plant’s operating conditions. Monitor acoustical and endurance properties of chute liners after their installation. Recommend additional suitable techniques and materials to reduce noise levels at the host facility.

These objectives were accomplished by completing the following four tasks:

**Task 1:** Evaluate noise reduction recommendations that were implemented after the initial phase of this work. Those measures that were implemented or planned for implementation included: dust/noise-reducing enclosures over vibratory screens, double-barrier blanket around the cylindrical part of a rotary breaker, rubber flaps in the rotary breaker inlet and discharge, and a new chute with acoustical/abrasion resistant liners.

**Task 2:** Evaluate additional chute liner material for erosion and impact resistance as well as noise level attenuation. Recommendations and protocols developed by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) were followed.

**Task 3:** Consult with the chute designer in order to incorporate recommended noise control materials. Proper chute design techniques coupled with selecting the most suitable materials for noise attenuation and durability/erosion resistance were the focus of these consultations.

**Task 4:** Conduct a final noise level survey after completion of all acoustical treatments of rotary breaker and vibratory screens including transfer chutes between them. Based on analysis of this survey, additional recommendations to achieve higher ambient noise level reductions were formulated.
INTRODUCTION AND BACKGROUND

Noise induced hearing loss (NIHL) is recognized as an occupational illness caused by long-term exposure to excessive sound levels. Exposure to elevated noise levels can cause not only noise-induced hearing loss, but also physiological stress, fatigue, cardiac abnormalities, and other health concerns. The noise standard established by MSHA requires the noise exposure level (NEL) for miners to be a time-weighted average not greater than 85dBA for an 8-hour exposure. At higher noise levels, exposure time must be decreased. No employee can be exposed to steady noise levels above 115 dBA regardless of their duration, or to impact or impulsive noise above 140 dB peak. The Code of Federal Regulations for occupational noise exposure defines permissible noise levels and provides for the use of “engineering and administrative controls to reduce the miner’s exposure to as low a level as is feasible” (30 CFR Part 62).

Noise levels measured in Phase I of this research were variable with intensity of coal flow (increasing with increasing flow) and in the noisiest areas were approaching the maximum level of 115 dBA. Peak noise was reaching 127 dB. The noisiest equipment was identified as the rotary breaker and vibratory screens. Plant personnel are currently required to wear dual noise protection that allows them to perform tasks in a limited time frame. Routine replacement of materials and structure in high wear areas provided the opportunity to incorporate improved designs that not only reduce noise levels, but are more abrasion resistant leading to improved service life.

Equipment available in the SIUC Acoustical Laboratory was used to investigate STL properties according to SAE J1400 standards. In addition, a sand blasting cabinet was purchased to investigate resistance to erosion of prospective high STL materials.

EXPERIMENTAL PROCEDURES

SAE J1400 standards for evaluating prospective noise barriers were adhered to in this project. The testing procedure and all SIUC facilities and equipment were described in the final technical report on Phase I of this study (Szary, 2012). The existing set-up was built to simulate steady working noise generating conditions typical of a coal handling facility. This set-up was modified to investigate impulse noise generated by the conversion of mechanical impact energy into transmitted acoustical energy. The new stand was built inside the existing reverberant room and is shown in Figure 1. This suite consists of the 400 m³ reverberation room joined to an anechoic chamber by way of a 0.5 by 0.5 m opening. Material samples being tested were carefully mounted and sealed along the edges in the opening between these rooms. Material dimensions and shape as well as the size of the opening determine fundamental and harmonic frequencies of the sample. Flanking and leaking noise levels were periodically checked. Reverberant room volume and sound absorption properties also determine the valid frequency range in which good results are expected. The reverberant room simulates the noisy environment of a coal handling facility and the new stand simulates a traveling mass delivering impulsive force and kinetic energy to the surface of the material being evaluated under carefully controlled conditions. Part of this energy is transmitted as an acoustical signal to
the anechoic chamber’s receiver. Since using coal or rock as the striking tip did not last longer than an average of three impacts before being destroyed, it was replaced by a wooden dowel that generated data similar in frequency and time domains to that produced by using coal. Samples tested in this arrangement included a steel plate simulating original material used in the plant’s transfer chute design. In addition, steel plates attached or bonded to polyurethane sheets and ceramic-embedded rubber liners were also tested. In coupled or composite materials, the “liner” side is facing the noisy environment and is exposed to the impulse/impact/impinging energy. Acoustical signals from the anechoic chamber and reverberant room were recorded in digital form from which information on time and frequency domain were extracted.

![Diagram](image_url)

*Figure 1: SIUC Acoustical Laboratory’s impact noise test apparatus.*

A second stand utilized a commercial sand blasting apparatus available from McMaster-Carr to simulate abrasive phenomena observed in plants conditions. The design and basic working principle of this stand are shown in Figure 2. The Model 3283K1 cabinet is equipped with a dust collector to remove the dust from inside of the cabinet. This blasting cabinet was connected to the existing acoustic laboratory compressed air delivery system. Two fixtures were design, built, and utilized in the chamber. The first one allows maintaining the sand firing gun at a constant intensity of air flow and a constant amount of sand in the air in line with the major axis connecting the gun’s muzzle with the sample’s center. The distance between the gun’s muzzle and the sample’s center was
constant. The second fixture allowed receiving the impinging sand stream at a precisely pre-set angle. The abrasive process was visually monitored and controlled and experimental consistency was secured by frequent inspection of pressure, air, and sand flow in delivering lines. Sample weight loss was measured using laboratory grade scales at SIUC’s Materials Laboratory. Time of sample exposure to abrasive sand stream was also precisely recorded.

![Diagram of sand blasting cabinet](image)

Figure 2: *Design (top) and working principle (bottom) of the sand blasting cabinet.*

After replacing the host plant’s main transfer chutes with ceramic-embedded polyurethane-lined material, noise levels were again surveyed. In addition to SPL readings in open air at select points, sound levels on the surface of the new chute were measured using the set-up shown in Figure 3. This arrangement allowed noise levels emanating from the surface of the chute to be measured without interference from other point sources or ambient noise levels in the plant.
RESULTS AND DISCUSSION

Task 1

SPL measurements in the host coal handling facility were expanded into the lower end of coal mass flow rate spectrum to include a value of 700 tons per hour (tph). Results of these measurements are incorporated with previous data from Phase I and are shown in Figures 3 and 4. The general trend of decreasing noise levels generated by equipment operating at decreasing flow rates was observed; however, average SPL oscillated around 100dBA for a coal flow rate of 700 tph, which is still higher than MSHA standards.

On Floor I (see Figure 3), the number of selected locations where measurements were performed was expanded from five to six. The added sixth location, marked as IIIa, is on the side of an acoustical barrier opposite the inlet chute to the rotary breaker. The acoustical barrier was a curtain similar to the STL barrier blanket used to cover the rotary blanket that was hung in the open space adjacent to the feed end of the rotary breaker. Comparing SPL measurements in Locations III and IIIa allowed for quantifying the effectiveness of the acoustical blanket, which is presented graphically as “Differential SPL” in Figure 5. For existing conditions, the effectiveness of this acoustical blanket as a free standing barrier was negligible from the lowest end of the acoustical frequency range up to 800Hz. Above 800Hz, the barrier is more effective. This blanket is designed to work as a STL barrier only, with almost no noise absorption properties. Because it is hygroscopic, it showed diminishing STL properties in the wet environment.

On Floor II (see Figure 4), the same trend of a decreasing SPL with decreasing coal flow rate was observed. On this floor, however, average SPL is about 2dBA less than SPL on Floor I for a coal flow rate of 700 tons/hr. Between the first and second phases of this project, crude dust enclosures were constructed over the discharge end of both vibratory screens. The noise survey conducted for this phase of the project indicates that these enclosures had absolutely no effect in reducing point source noise generated by the screens. Granted, these enclosures were built solely for dust control purposes, but it was hoped that they would impact noise levels, even if only to a small extent. Therefore, results were disappointing.
Figure 3: SPL measurements for varying intensities of coal mass flow at selected locations on Floor I.
Remarks: Location of the Sound Pressure Level Meter to obtain noise level data, second floor of a Coal Handling Plant. All measurements: 1.5m above floor level and 1 m from the source.

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Figure 4: SPL measurements for varying intensities of coal mass flow at selected locations on Floor II.
Figure 5: Measurements on either side of acoustical blanket noise barrier adjacent to rotary breaker inlet chute.
Task 2

Noise Level Attenuation

Various conveyor belt material and configurations were tested in SIUC’s acoustical laboratory for STL according to SAE J1400 standards. In addition, ethylene-vinyl-acetate (EVA) noise reducing blankets and polyurethane plates typically used in the automotive industry were tested as good candidates for design of single- and double-barrier systems suitable in coal plant applications.

Results of STL tests on conveyor belt materials as single- and double-barrier systems are shown in Figure 6. Actual values from STL testing in the SIUC Acoustic Laboratory are given in Table 1. A double-barrier system consisting of two identical barriers with minimal coupling is assumed to provide double the STL of the single barrier system. Conveyor belting with a thickness of 0.453” shows better STL properties than the acoustical blanket currently in use. This material can be used to build single- or double-barrier acoustical enclosures around noisy devices that would achieve very high STL; however, a double-barrier enclosure would have substantial weight to it.

Considering STL-to-weight ratio of acoustical panels as an optimization criterion for a good enclosure design, material similar to automotive EVA or 1/16” steel plate lined with attached polyurethane sheets give the best results. These materials in a double-barrier configuration will effectively reduce noise generated by any enclosed device.

Figure 6: Noise reduction achievable with single- and double-barrier systems made from conveyor belt material of varying thickness.
Table 1: Sound transmission loss for a single barrier system.

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<tr>
<th>Frequency (Hz)</th>
<th>Sound Blanket $\rho_s = 7.44$ kg/m²</th>
<th>Virgin Polyurethane $\rho_s = 17.2$ kg/m²</th>
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Impact Resistance

Laboratory analysis of recorded peak/impact noise shows that it is proportional to the size of solids striking the rotary breaker’s feed chute liner plates, as well as tumbling inside the breaker. Since the elevation (vertical) distance of solids dropping in the chute is fixed, their kinetic energy is linearly proportional to their mass. The density difference between coal and rock plays a role in the amount of impact acoustical energy transferred into the air. Sound levels transmitted through the acoustical coupling between the chute’s plates and objects striking it are larger for rock than for coal. This physical property needs to be considered in the process of choosing the proper chute liner.

In laboratory experiments, the difference in frequency spectrum and air vibrations of transmitted impulse noise generated by stone and wooden blocks striking a plate was measured. Wooden blocks were chosen to represent coal as experiments with coal ended prematurely due to the coal breaking up. Results are shown in Figure 7. The stronger energy transfer factor between stone and steel plate developed a significant transient
response in the steel plate and transferred peak noise through the plate. The effect was much larger for stone than for wooden blocks. Time domain graphs are used to calculate the internal damping factor of the plate, which determines transmitted peak noise level.

Results of wooden blocks and stone striking the vinyl side of a vinyl-steel composite panel are shown in Figure 8. This experiment simulates the chute wall with installed liner. The liner with high STL properties significantly reduces transient response of the composite. Larger amounts of dissipating energy in the vibrating plate were observed.
Figure 8: Impulse noise generated by striking a vinyl/steel composite plate.

Erosion Resistance

Several liner materials already shown to have good STL properties were also tested in laboratory conditions for resistance to abrasion. Material samples were subjected to an impinging sand stream at a precisely set angle and sample weight loss was measured at different time intervals. Results, shown in Figure 9, indicate that samples of ceramic-embedded vinyl manufactured for Richwood Industries to build high STL and abrasion-resistant liner plates under the name of “Rock Plate” were lasting approximately twice longer in laboratory abrasion test conditions than the equivalent steel plate. Other man-made plastic type materials with high STL properties, such as low density polypropylene, were eroding several times faster than the steel plate. Of these materials, polyurethane shows better abrasion resistance than other materials.
Task 3

The noise energy balance for a lined chute wall is shown in Figure 10. The chosen liner element for the composite single wall of the chute is Richwood Industries’ “Rock Plate.” The impinging noise energy from the interior side of the panel is partially reflected on two contact surfaces. Much of the noise energy is also absorbed (creating periodical motion) in the liner and in the steel plate. The remainder is transmitted through the chute’s exterior where it becomes part of the ambient noise of the plant. The same mechanism of energy transmission is observed for noise energy traveling from the plant’s ambient air into the chute’s interior. Figure 10 also shows the method of measuring noise levels emitted from the chute’s surface.

Laboratory results were shared with an engineering firm tasked by the host plant with designing, manufacturing, and replacing transfer chutes between both vibratory screens and the rotary breaker. Figure 11 shows schematics of the redesigned chute work with dashed lines representing surfaces lined with the “Rock Plate” material. Figures 12-14 show sections of the lined chute in the yard before installation. Figure 15 shows final installation of the bottom section of the chute where it feeds the rotary breaker.
Figure 10: Noise energy balance in chute wall.

Figure 11: Schematic of replacement transfer chute for host plant.
Figure 12: Top of chute – vibratory screen discharge hopper.

Figure 13: Bottom of chute – inlet to rotary breaker.
Figure 14: Main section of transfer chute wall lined with “Rock Plate.”

Figure 15: Bottom section of installed chute feeding the rotary breaker.
Task 4

Installation of the new chute was completed in April 2014. After installation, a new noise survey was conducted. This survey revealed that measured impulse (peak) noise was reduced from 127 to 114dB and steady noise around the chute’s exterior surface was on average 7dBA less.

CONCLUSIONS AND RECOMMENDATIONS

To effectively lower ambient noise levels in coal handling facilities requires installation of enclosures with very high overall STL properties. In the host plant where noise surveys were conducted, the primary equipment requiring noise treatment consisted of the rotary breaker and vibratory screens. Sound damping blankets have been used to cover or enclose the rotary breaker and plastic curtain enclosures have been placed over vibratory screens for dust control purposes. Neither of these techniques has proven to be significantly effective.

Noise control enclosures need to be built that are “air tight” to minimize noise escaping from controlled areas. They need to be designed for 50dB STL in the 1000 Hz frequency range. The weight of these enclosures will be added to existing structures and will influence the overall dynamic behavior of the facility. To minimize this effect, the weight of enclosures should be kept as low as possible.

Double-barrier systems, which have better STL-to-weight ratios, are better suitable for coal handling facilities than single-barrier designs. Laboratory tests of suitable materials for STL enclosures showed that EVA used in the automotive industry provides very good weight-to-volume ratio. An EVA sheet (or similar material) permanently bounded to steel plate increases STL and has the durability to work well in wet and dusty environments.

Reducing high-level impulse noise from rock impacting transfer chute plates was accomplished by applying typical STL barriers on the mass impact/impinging side. This reduced transmitted impulse noise levels with their associated harmonics. The “Rock Plate” liner was selected for use in a redesigned transfer chute feeding the rotary breaker. This liner attached to the interior of the steel chute created a single composite STL barrier. Measured impulse (peak level) noise was reduced from 127 to 114dB and steady noise levels on chute’s exterior surface were on average 7dbA less.

Different prospective STL barrier materials were also tested in laboratory conditions for resistance to abrasion. Results showed that “Rock Plate” samples showed the highest resistance to abrasion. They were lasting approximately twice longer in laboratory abrasion test conditions than the equivalent steel plate. Other materials with high STL properties, such as low density polypropylene and polyurethane, were eroding several times faster than the steel plate.
REFERENCES


DISCLAIMER STATEMENT

This report was prepared by Dr. Marek Szary of Southern Illinois University, with support, in part, by grants made possible by the Illinois Department of Commerce and Economic Opportunity through the Office of Coal Development and the Illinois Clean Coal Institute. Neither Dr. Marek Szary, Southern Illinois University, nor any of its subcontractors, nor the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development, the Illinois Clean Coal Institute, nor any person acting on behalf of either:

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